Defence Research and Development Canada Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Radar Signature Control Using Metamaterials

L. Varga

Defence R&D Canada – Ottawa

TECHNICAL MEMORANDUM
DRDC Ottawa TM 2004-265
November 2004

Canada

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 2004**	2. REPORT TYPE	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Radar Signature Control Using Metamaterials (U)**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence R&D Canada -Ottawa,3701 Carling Ave,Ottawa Ontario,CA,K1A 0Z4**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
A method enabling the control of the radar signature using metamaterial is presented. The work was carried out using a Multiradius Bridge Current (MBC) Electromagnetic Moment Method code. The metamaterial specimen in this work is a 2D array of vertical wire segments each loaded with resistor and inductor. The results indicate that the far field directional gain of the metamaterial differs from the specular far field directional gain of a wire mesh. In case of the metamaterial, the far field directional gain can be rotated in azimuth with respect to the direction of the incoming incident wave. The results are discussed in term of activated segment line selected from the array of segments that make up the metamaterial specimen.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**30**	

Radar Signature Control Using Metamaterials

L.Varga
Defence R&D Canada – Ottawa

Defence R&D Canada – Ottawa

Technical Memorandum

DRDC Ottawa TM 2004-265

November 2004

Abstract

A method enabling the control of the radar signature using metamaterial is presented. The work was carried out using a Multiradius Bridge Current (MBC) Electromagnetic Moment Method code. The metamaterial specimen in this work is a 2D array of vertical wire segments each loaded with resistor and inductor. The results indicate that the far field directional gain of the metamaterial differs from the specular far field directional gain of a wire mesh. In case of the metamaterial, the far field directional gain can be rotated in azimuth with respect to the direction of the incoming incident wave. The results are discussed in term of activated segment line selected from the array of segments that make up the metamaterial specimen.

Résumé

Une méthode permettant le contrôle de la signature radar utilisant du métamatériel est présentée. Les travaux ont été menés en utilisant un code de moment électromagnétique avec la méthode MBC. Le spécimen métamatériel dans ce travail est une grille 2D de segments verticaux dont chacun sont chargés avec résistance et inductance. Les résultats indiquent que le gain directionnel de champ éloigné du métamatériel diffère du gain directionnel du champ éloigné spéculaire d'un treillis métallique. Dans le cas du métamatériel, le gain directionnel du champ éloigné peut être tourné dans l'azimut par rapport à la direction de l'onde entrante incidente. Les résultats sont discutés par rapport à la ligne de segment activée choisie de la grille de segments qui composent le spécimen métamatériel.

This page intentionally left blank.

Executive summary

Enemy radar uses Radar Cross Section (RCS) to identify a military platform. An attempt to deny such recognition is therefore a long-standing effort of every military. Reducing or changing the RCS of a platform has been carried out by using techniques such as covering key structures with Radar Absorbing Materials (RAM) or altering parts of the structure with mesh such as the Salisbury screen. The signature in both cases is altered, by converting energy of the impinging radar wave into heat.

A different approach to changing and even managing RCS is the ability to control the reflection of the radar wave by means of redirection in some direction other than a specular direction. Such a material could then be made into sheets of size similar to the presently used RAM.

Metamaterials are materials with interesting electromagnetic properties such as controllable permitivity and permeability, which in turn affect the refractive index of the material and the propagation of radar waves trough it. It is an engineered material, made by embedding circuit elements in an array-like fashion into a dielectric substrate. As an example such circuit elements could be made up of capacitors, inductors and resistors, split-ring resonators or parallel wires.

This work, carried out under a TIF project, presents the results of RCS management using metamaterials. For comparison purpose, the RCS of a wire mesh reflector is also given. The results were obtained by using a Multiradius Bridge Current (MBC) Electromagnetic Moment Method code. The metamaterial specimen in this work is a 2D array of vertical wire segments loaded with resistors and inductors. The specimen is 50 cm by 50 cm square having thickness of 5 mm.

Preliminary results indicate that the far field pattern of the metamaterial is not oriented along the direction of the incoming incident wave as is in the case of the wire mesh (i.e. specular) but at some other, controllable direction.

Varga L. 2004. Radar Signature Control Using Metamaterials. DRDC Ottawa TM 2004-265. Defence R&D Canada - Ottawa.

Sommaire

Le radar ennemi emploie le ‘‘RCS’’ pour identifier une plateforme militaire. Toute tentative de camoufler une telle identification est donc un effort de longue date de chaque militaires. La réduction ou l’altération du RCS d'une plateforme a été effectué en employant des techniques telles que de couvrir les structures principales de matériaux absorbants de radar (RAM) ou de changer des parties de la structure avec de la maille telle que l'écran de Salisbury. La signature dans les deux cas est changée, en convertissant l'énergie de l’onde de radar en chaleur.

Une approche différente pour modifier ou même gérer le RCS est la capacité de commander la réflexion de l’onde de radar au moyen de redirection dans une certaine direction autre que la direction spéculaire. Un tel matériel pourrait donc être transformé en feuilles de taille semblables à la RAM actuellement utilisée.

Les métamatériaux sont des matériaux avec des propriétés électromagnétiques intéressantes telles que la permittivité et la perméabilité contrôlables, qui affectent à leur tour l'indice de réfraction du matériel et la propagation des ondes radar les traversants. C'est un matériel ingéniré, fait en incluant des éléments de circuit d’une manière organisée en grillage dans un substrat diélectrique. Un exemple de tels éléments de circuit pourrait se composer de condensateurs, d’inductances et de résistances, de résonateurs ‘‘split ring’’ ou de fils parallèles.

Ces travaux, menés sous un projet ‘‘TIF’’, présentent les résultats de la gestion de RCS en utilisant des métamatériaux. Pour fins de comparaison, le RCS d'un réflecteur de treillis métallique est également donné. Les résultats ont été obtenus en employant un code de moment électromagnétique avec la méthode MBC. Le spécimen métamatériel dans ce travail est une grille 2D de segments verticaux chargés avec résistance et inductance. Le spécimen est de 50 centimètres par 50 centimètres avec une épaisseur de 5 millimètres.

Les résultats préliminaires indiquent que le patron du champ éloigné du métamatériel n'est pas orienté le long de la direction de l’onde incidente comme il l’est dans le cas du treillis métallique (c.-à-d. spéculaire) mais dans une autre direction contrôlable.

Varga L. 2004. Radar Signature Control Using Metamaterials. DRDC Ottawa TM 2004-265. R & D pour la défense Canada - Ottawa.

Table of contents

List of figures

1. Introduction

Reducing Radar Cross Section (RCS) of a military platform increases its survivability by minimizing its signature and thus the threat from being targeted by hostile radar guided missiles. Reducing or changing the RCS of Canadian military platforms has therefore been an ongoing research effort at DRDC Ottawa. Computer simulation and experimental measurements utilizing Radar Absorbing Materials (RAM) to reduce and change the RCS of a naval vessel have been performed for a number of years. RCS measurements have been made for various Canadian navy ships such as HMCS Athabaskan, HMCS Protecteur, HMCS Halifax and the Glen class coastal tug to name a few [1].

Another approach to manage RCS of a platform is to be able to actively control the reflection capability of the material that would cover parts of a vessel in lieu of RAM. The successful development of such material would therefore provide the capability of adaptive radar signature management. This potentially stealth technology would, besides making detection more difficult, also provide the means of changing the radar image of the targeted platform. Development of such material would lead to planar structures that can be used to retrofit existing platforms or designed to be used with the new ones. The size of such material sheet could be in the order of 1 to 2 meters, a size similar to a size of a presently used RAM sheets [1]. Such a material, would, instead of absorbing the energy of the radar wave, redirect the incoming radar wave to some other direction than specular. The work prescribed here aligns with the DRDC R&D Investment strategy objective, specifically to “signature management”. The work is being carried out under the Technology Investment Funds program and is aimed to study RCS management utilizing new materials called “metamaterials”.

Metamaterials constitute a rapidly expanding new technology with number of applications, many of them with clear relevance to DND such as the above mentioned area of radar signature management. These are engineered materials manufactured by implanting into a dielectric medium an array of small resonant circuits. These resonant circuits can be in various forms, for example an inductor, capacitor and resistor resonant circuit [2] or split ring resonator[3] or in the form of parallel wires. Metamaterials can be relatively easily fabricated using standard single-sided or double-sided printed-circuit technique.

In this report the means of managing the scattering of microwaves, reflected from surfaces of metallic objects is presented. The specimens under study were 50cm x 50cm wire mesh and a material made from an array of vertical wire segments loaded with resistors and inductors. The results were obtained via computer simulation using a Multiradius Bridge Current (MBC) Electromagnetic Moment Method code. This document provides information about the simulation set up, description of the specimens and far field results.

2. Simulation set up

Figure 1 depicts the simulation set-up, showing a specimen situated over a perfectly conducting ground. A 3.4GHz microwave was impinging on the specimen from the direction $\Theta = 45^o$ (Θ (Theta) = elevation angle) and Φ angles of 0^o, 45^o, and 90^o (Φ (Phi) =azimuth angle). The incident wave polarization in all cases was vertical with the exception of one case, where the electric field of the incident wave had horizontal polarization (Section 4.7).

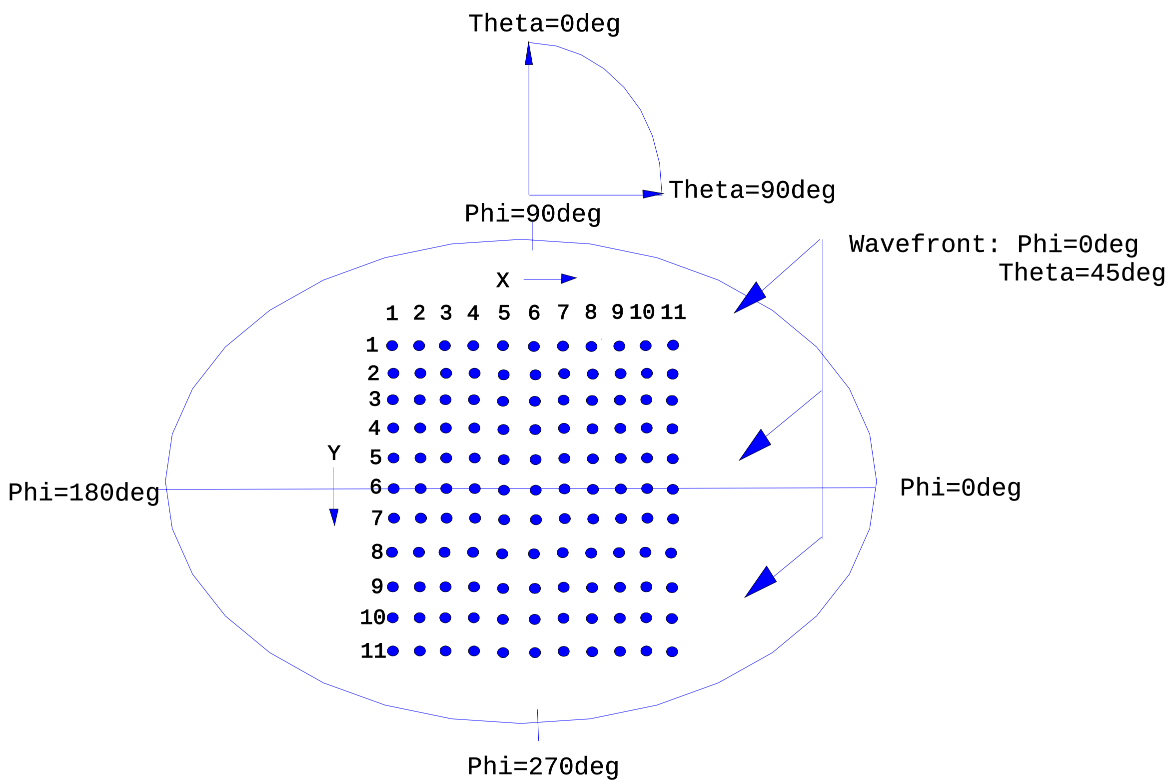


Figure 1. Schematic diagram of the simulation set-up showing the specimen, the incoming incident wave direction and the pertinent geometry. The angles Φ (Phi) and Θ (Theta) are angles of azimuth and elevation.

3. Description of the specimens

3.1 Wire Mesh Specimen

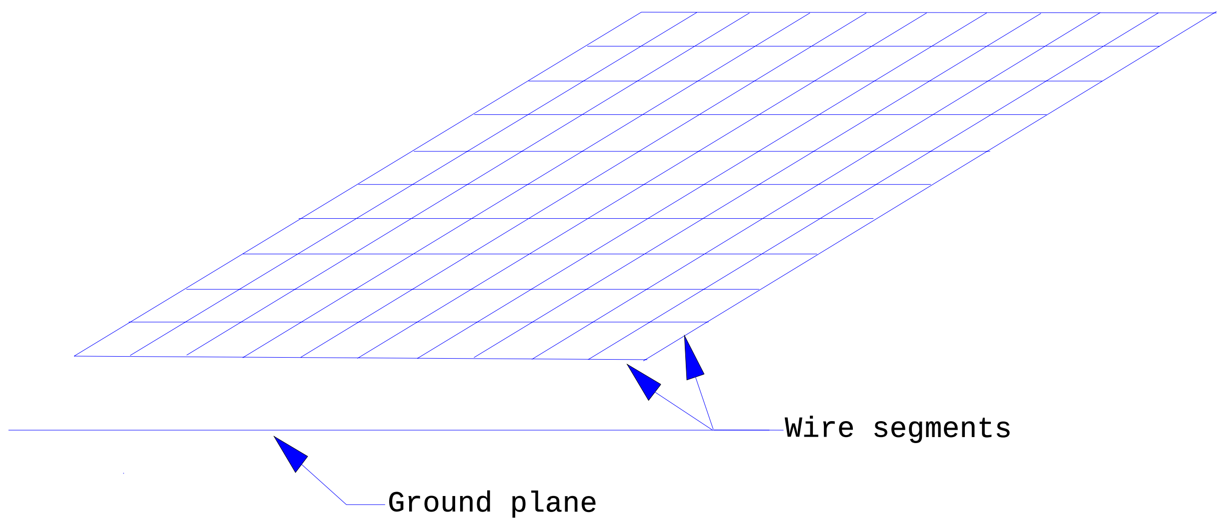


Figure 2. A ten segments by ten segments wire mesh above ground**.**

3.2 Metamaterial Specimen

Figure 3 is a schematic diagram of the metamaterial specimen and the individual components. The individual components are made of thin vertical wire loaded with inductors and resistors. In this study the substrate of the metamaterial is air. The components are spaced (L) 5cm in X and Y direction (see also Figure 1 and 3) and have the height (H) of 5 mm. The wires have thickness of 0.1000E-04 m and conductivity of 0.5800E+08 S/m. The inductors have inductance of 0.25E-07 Henrys and the resistors have resistance of 1.6 Ohms. The simulations were conducted by keeping a line of loaded wire segments along the selected direction “ON” (activated) while the other wire segments in the array were turned “OFF” (deactivated). The deactivation was simply accomplished by replacing the small loading 1.6 Ohms resistors with a large 160 Mega Ohms resistors. The selected activated lines had directions along the $\Phi = 90^{o}$, $\Phi = 45^{o}$ and $\Phi = 135^{o}$, shown in green in Figure 2.

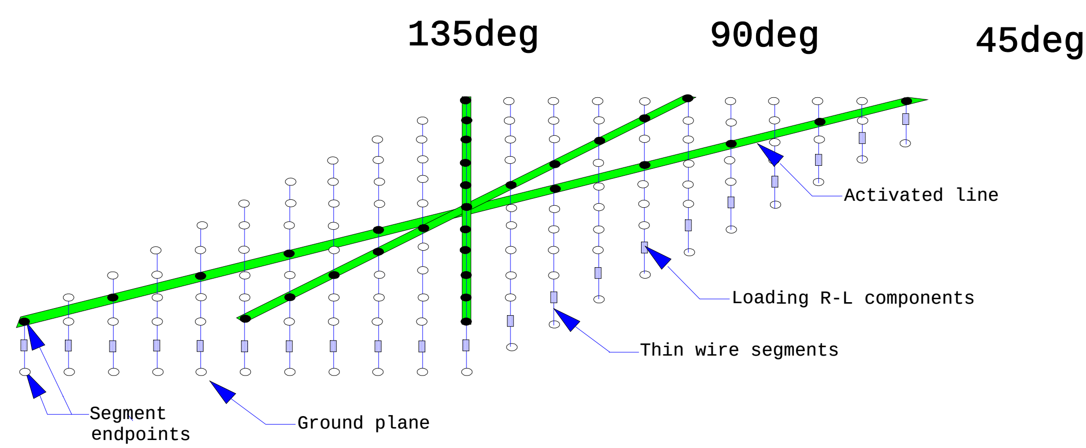


Figure 3. The metamaterial specimen with components. The activated line directions used in this work are shown in green...

Figure 4 shows two types of wire segment connections, named type-A and type-B that were used to create the metamaterial specimen. The type-B connection differs from type-A in that at the ground level all the wire segments are connected to the same point. This type of segment connection was used in the activated line. Type-A segment connection formed the rest of the metamaterial array.

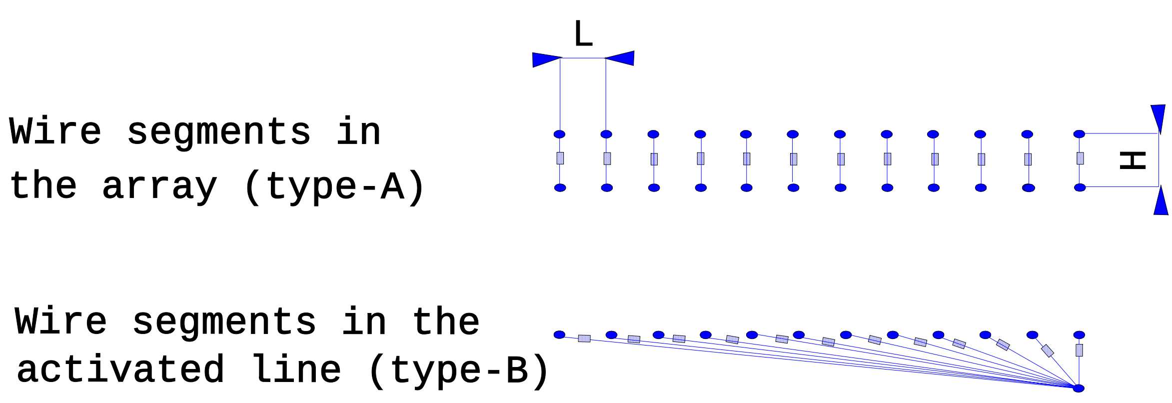


Figure 4. Wire segments in type-A and type-B connection. L is the distance between elements in the array and was set to 5cm and H is the height above ground and was set to 5mm. In both cases, the wires are loaded with inductors and resistors.

4. Results

4.1 Wire Mesh

Figure 5 is the far field directivity gain pattern defined as ratio with respect to an isotropic radiator. Panels (a) and (c) show the vertical component of the directivity gain (D_gain_Θ) in elevation and elevation and panel (c) is the horizontal component of the directivity gain (D_gain_Φ) in azimuth. Prominent directivity gain is evident in (a) showing strong back reflection component and small in a forward direction. It should be pointed out that the reflection pattern was observed to be dependent on the mesh size. For example at the mesh size of 1.0cm the forward reflection is larger then the back reflection.

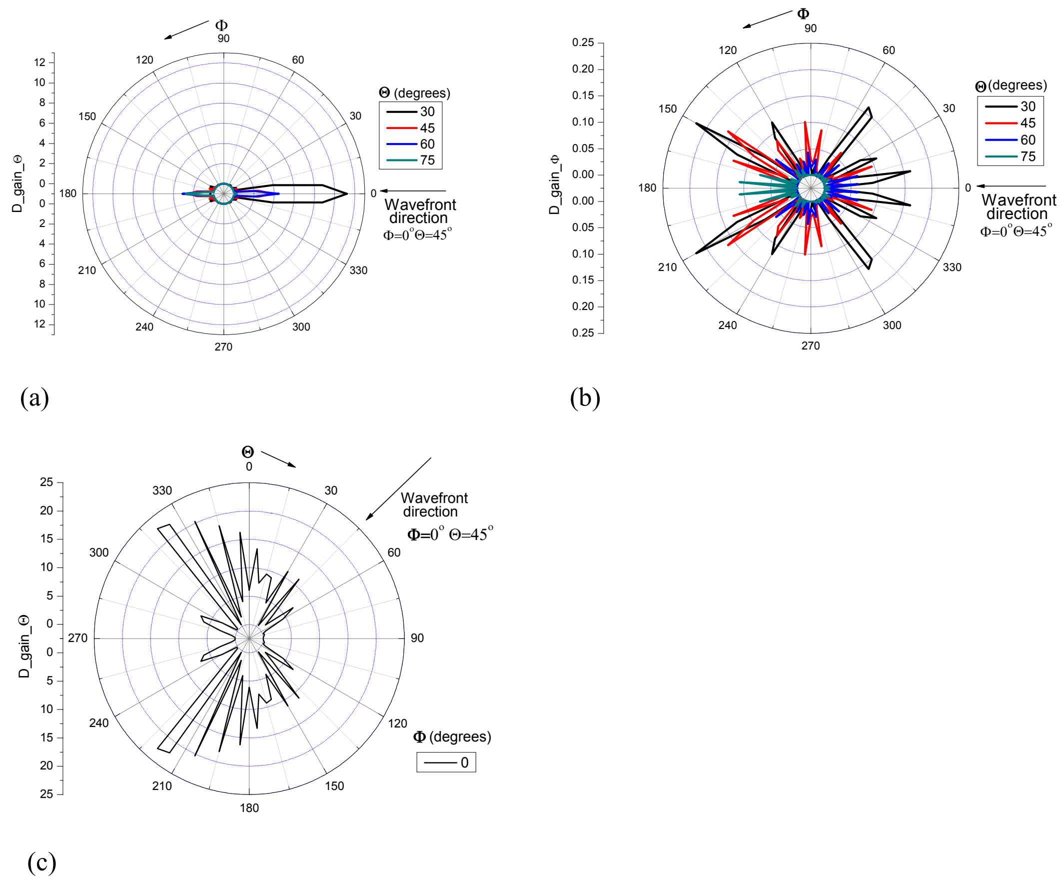


Figure 5. Far field directivity results for a wire mesh above ground with components as shown. Panels (a) and (b) are directional gains in azimuth and (c) is directional gain in elevation.

4.2 Metamaterial with activated line along $\Phi = 90^o$

Various configurations of circuit elements inserted into a dielectric medium qualify as metamaterials [2,3,4]. Wider range of types of metamaterial specimen than presented here has been tested as possible candidates for control of the far field signature. Results for some of them so far obtained are inconclusive and therefore at this time are not discussed in any detail. The results presented here have been obtained with the specific metamaterial specimen described in Section 3.2. The activated line in Figure 6 is a line of segments that have the loading resistors set to a much smaller value than the loading resistors of the segments in the rest of the array. The activated line (see Section 2) was along the direction $\Phi=90^o$. The connection of wires in the activated line was type-B as described in Figure 3(b). In the rest of the array, the segment connection was type-A. The results show that the theta component of the far field directionality is turned along the activated line direction (panel (a) in Figure 6). Figure 7 shows the voltage phase distribution at the surface of the metamaterial. Voltage phase shift pattern is evident in X=6 line, which is the activated segments line. What happens if instead of using type-B connection in the activated line one uses type-A is shown in section 4.3.

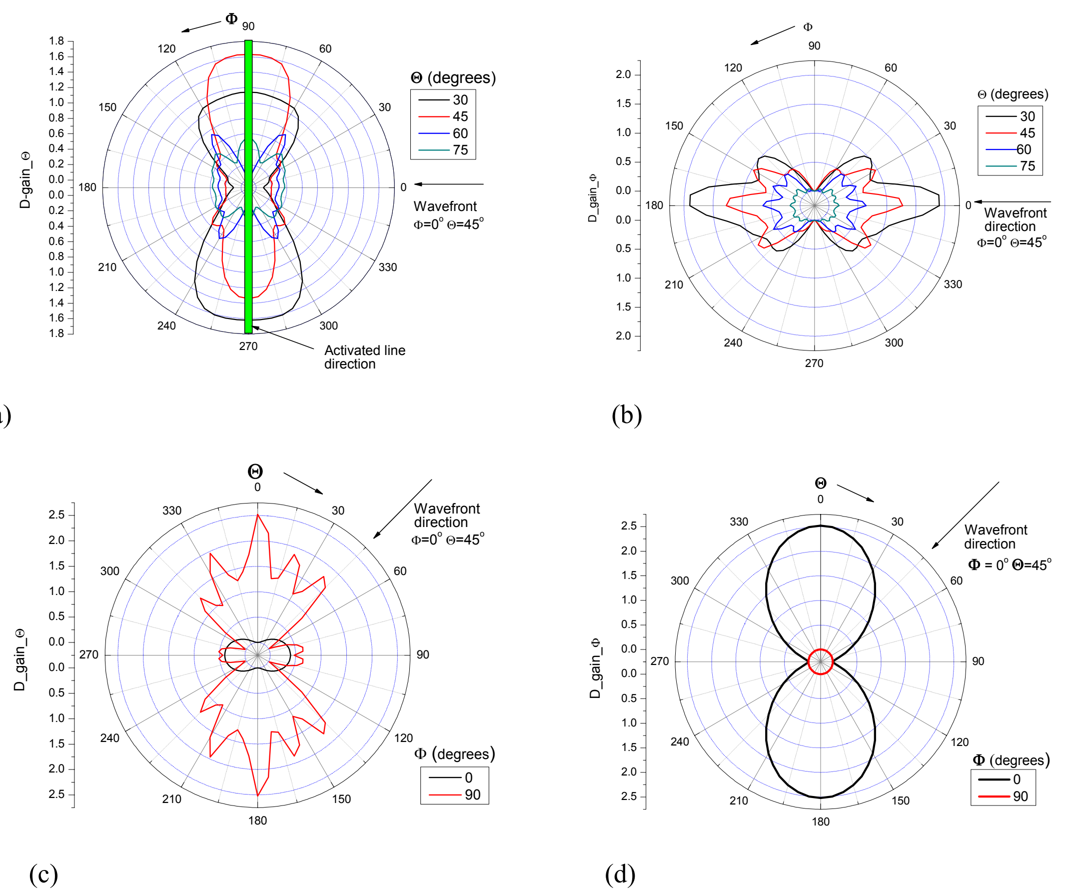


Figure 6. Far field directional gain (power ratio) results, where (a) and (c) are the Θ components of the directional gain in azimuth and elevation and (b) and (d) are the Φ components of the directional gain in azimuth and elevation. The incident wave is approaching from $\Phi=0^o$, $\Theta=45^o$ and the electric field is vertically polarized.

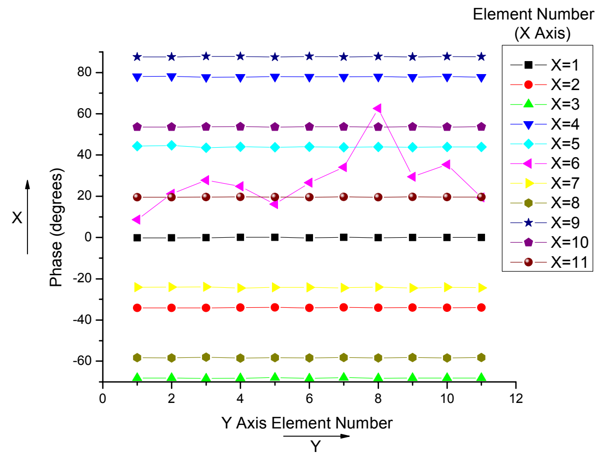
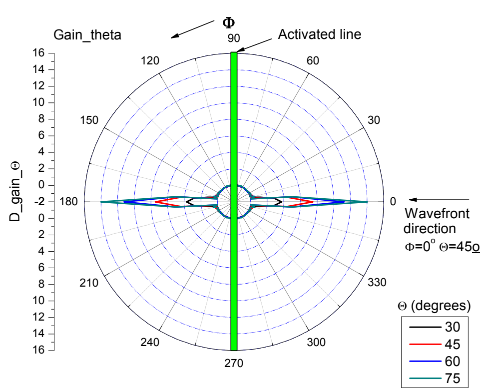


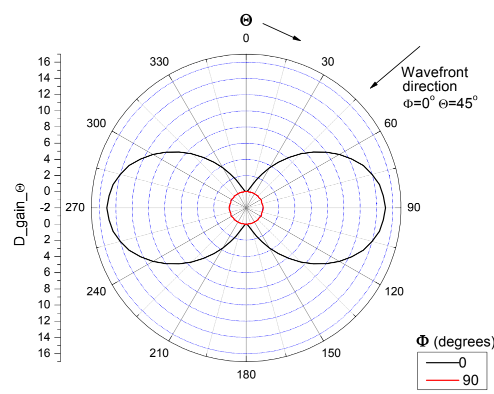
Figure 7. Voltage phase of the individual metamaterial elements. A specific phase variation from element to element is evident in the activated line (x=6), but not on the other elements of the array. However, a progressive phase variation appears along the X-direction, i.e. the incident wave front direction.

4.3 Metamaterial with activated line along Φ = 90^o (Type-A segment connection in activated line)

Figure 8 shows the far field directivity pattern is along the Φ = 0^o Φ=180^o meridian, which is the same as the incident wave direction. No rotation occurs and the Θ component results resemble the far field directivity results of the wire mesh.



(a)



(b)

Figure 8. Far field directional gain results using type-A segment connection in the activated line. The direction of the activated line is along the Φ=90 degrees, shown as green line. The Φ component of the gain is equal to zero. The direction of the incident wave is also shown; the incident wave was vertically polarized. Panel (a) shows the far field in azimuth and (b) in elevation.

4.4 Metamaterial with activated line along Φ = 135°

A line of segments was activated along the $\Phi=135^{\circ}$ meridian and as shown in Figure 9 with the incident wave coming from $\Phi=0^{\circ}$. However the directivity of the Θ component is not along the activated line but perpendicular to the activated line. The Φ main directional gain component is in the direction $\Phi=150^{\circ}$. The results here show that only minimum is reflected along the incident wave direction.

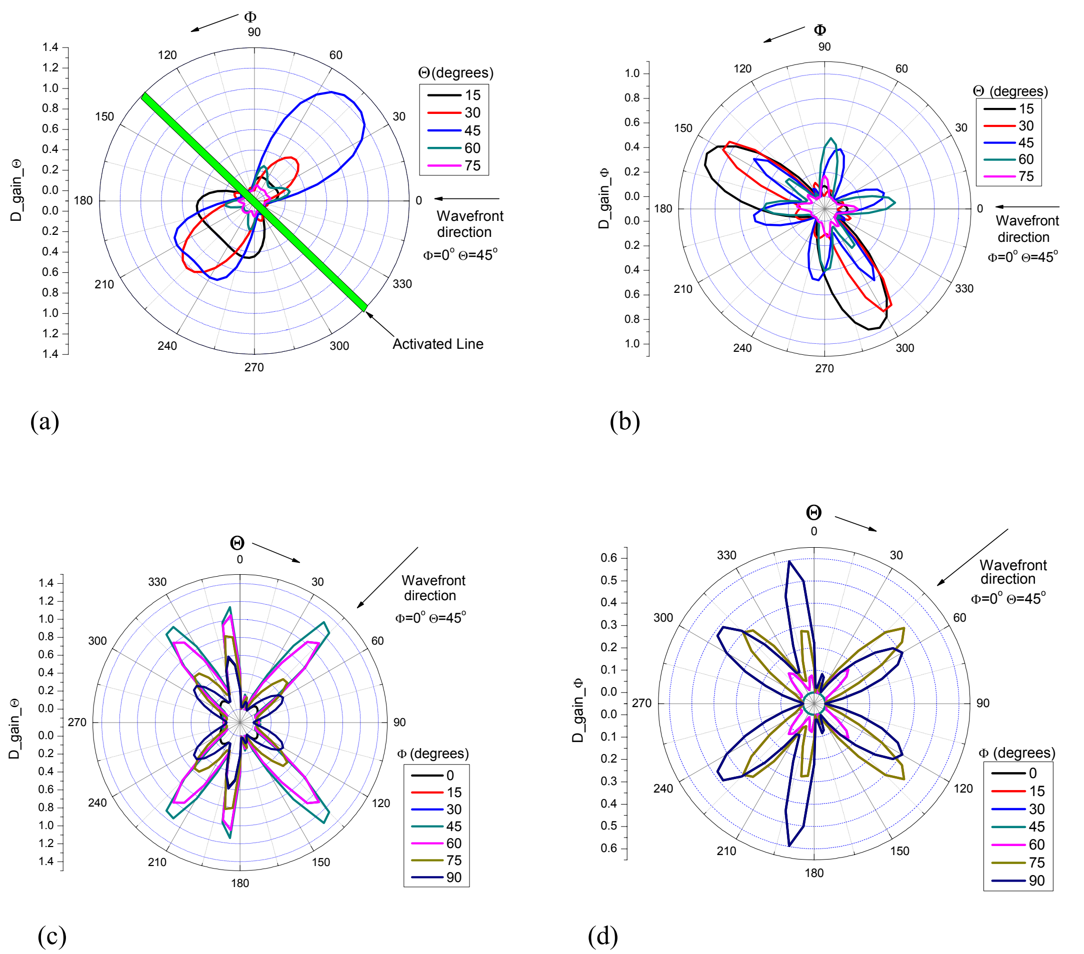


Figure 9. Far field result using type-B segment connection with the activated line along Phi $=135^{\circ}$ as shown with green line. Panels (a) and (c) are the Θ directional components of the gain in elevation and azimuth and (b) and (d) are the Φ components of the gain. The incident wave is approaching from $\Phi=0^{\circ}$, $\Theta=45^{\circ}$ and the electric field is vertically polarized.

4.5 Metamaterial - incident wave direction effect

4.5.1 Activated line along the $\Phi=90^{o}$

This section gives. Three directions were selected, namely incident wave approaching from Phi=0^{o}, Phi=45^{o} and Phi = 90^{o}. In all the cases, the incident wave was vertically polarized. As shown in Figure 10, the line was activated along the $\Phi=90^{o}$ (see also to Figure 2). The results show that the directivity of the far field is always along the direction of the activated line and does not appear to be influenced by the direction of the incidence.

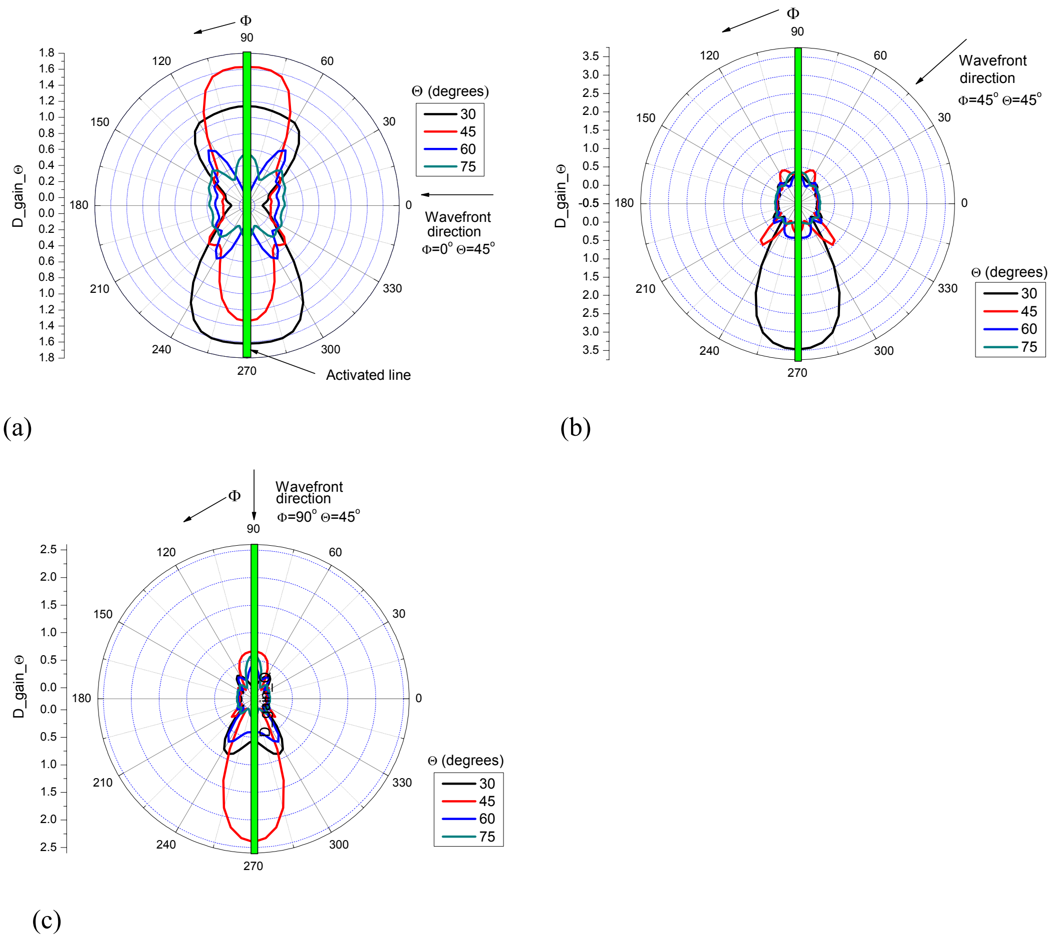


Figure 10. Activated line (type-B connection) along $\Phi=90^{o}$. Far field directional gain results: (a) incident wave direction $\Phi=0^{o}$, (b) incident wave direction $\Phi=45^{o}$ and (c) incident wave direction $\Phi=90^{o}$.

4.6.2 Activated line along the Φ=45°

Again, as in the previous case, the approaching incident wave directions were Φ=0°, Φ=45° and Φ = 90°. In all the cases, the incident wave was vertically polarized. As shown in Figure 11, the line was activated (type-B connection) along the Φ = 45°. The results show that the directivity of the far field is always at the right angle with respect to the direction of the activated line and does not appear to be influenced by the direction of the incident wave.

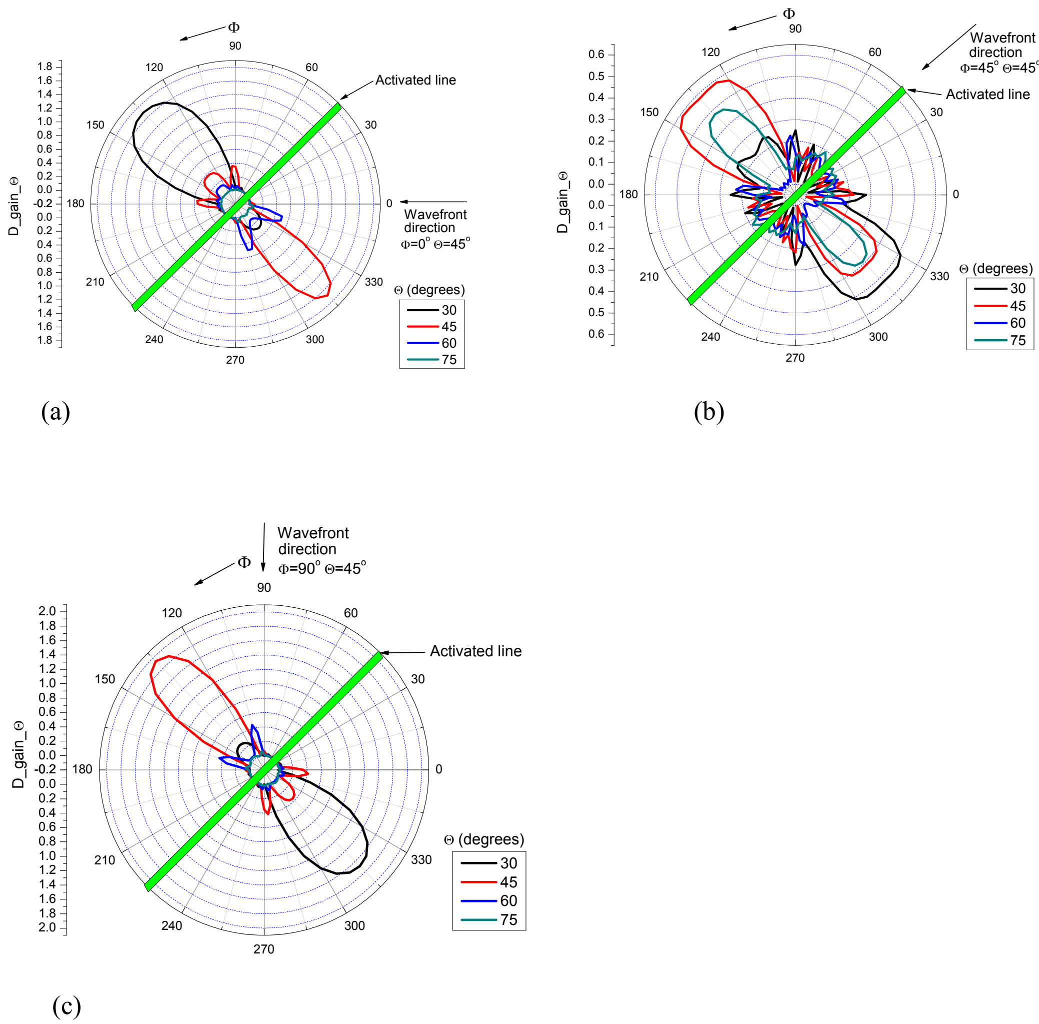
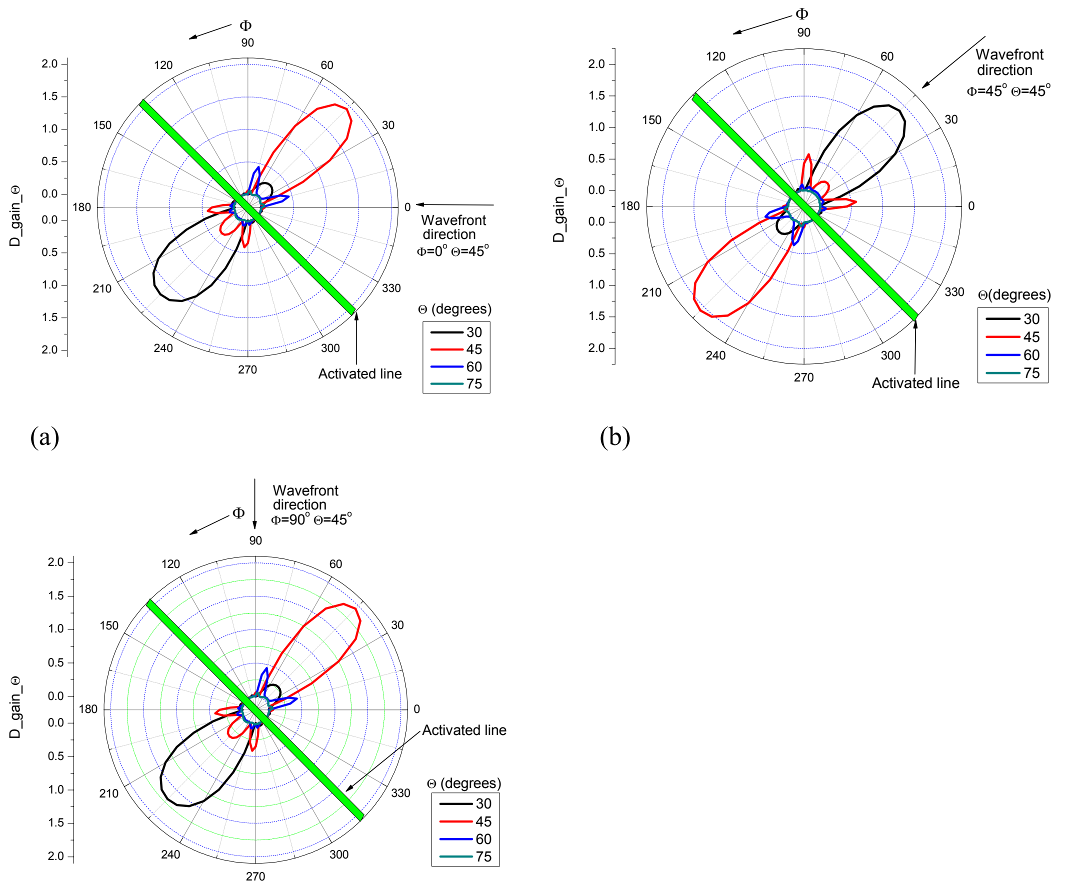


Figure 11. Activated line (type-B connection) along Φ=45°. Far field gain results: (a) incident wave direction Φ=0°, (b) incident wave direction Φ=45° and (c) incident wave direction Φ=90°.

4.6.3 Activated line along the Φ=135°

The approaching incident wave direction has not influenced the far field directivity, which again was perpendicular to the activated line (type-B connection) direction as shown in Figure 12. This however would be less desirable if the incident wave is approaching from the direction of Φ = 45° because this scenario would provide backscatter in the direction of the approaching incident wave. Note that other incident wave directions are satisfactory.



(a) (b) (c)

Figure 12. Activated line (type-B connection) along Φ=135°. Far field gain results: (a) incident wave direction Φ=0°, (b) incident wave direction Φ=45° and (c) incident wave direction Φ=90°.

4.7 Metamaterial – horizontal polarity incident wave

The far field directionality has two components, and again the theta component is oriented along the direction of the activated line, while the phi component along the direction of the approaching incident wave. Both components have a strong vertical directionality.

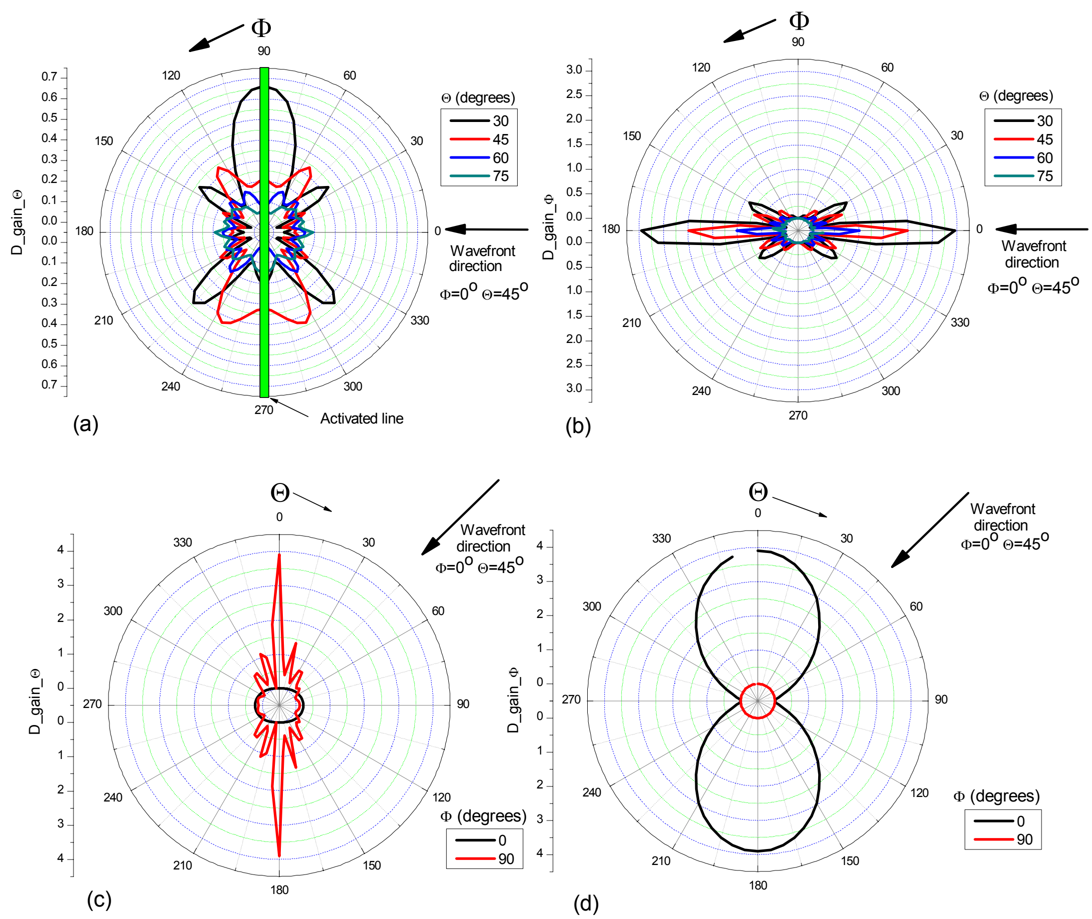


Figure 13. Far-field directional gain results. Panels (a) and (c) are the Θ components of the directional gain in elevation and azimuth and the panels (b) and (d) are the Φ components of the directional gain. The incident wave is approaching from Φ=0°, Θ=45° and the electric field is horizontally polarized.

5. Summary

Far field computer simulation results of a microwave incident wave reflected from a planar wire mesh and metamaterial specimen were presented. Preliminary simulation results have revealed that reflection of microwaves from metamaterial can, under specific conditions generate far fields that differ from the far field of a wire mesh and for that matter also from a metal plate. Metamaterials can also provide some degree of control over the far field results by utilization of the so-called “activated line” as discussed in section 2. More specifically, an activated line composed of type-B segment connection, the far field directional gain Theta component was rotated in azimuth that was different from the direction of the incident wave i.e. different from specular. The direction of rotation was dependent on the direction of the activated line. Results have also shown that using an A-type connection inside the activated line instead of the B-type, the directional gain was comparable to the wire mesh far field result, i.e. specular.

References

1. S. Kashyap, A. Louie, G. Farley and D. Boivin (2004). The near-field RCS of the tug Glenside: measurement vs. computations. (DRDC Ottawa TM 2004 – 099). Defence R&D Canada – Ottawa.

2. K.G. Balmain, A.A.E. Lüttken and P.C. Kremer, "Resonance Cone Formation, Reflection, Refraction and Focusing in a Planar, Anisotropic metamaterial", IEEE Antennas and Wireless Propagation Letters, 1(7), 2002.

3. E. Ozbay, K. Aydin, E. Cubukcu and M. Bayindir, Transmission and Reflection Properties of Composite Double Negative Metamaterials in Free Space", IEEE Transactions on Antennas and Propagation, Vol. 51, No. 10, October 2003.

4. Marqués, R., Baena, J.D., Martel, J., Medina, F., Falcone, F., Sorolla, M., and Martín, F. (2003). Novel Small Resonant Electromagnetic Particles for Metamaterial and Filter Design. In *Proceedings of the ICEAA 03*, 439-442. Torino, Italy.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – Ottawa 3701 Carling Ave., Ottawa, K1A 0Z4, Canada	2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable) UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

Radar Signature Control Using Metamaterials (U)

4. AUTHORS (Last name, first name, middle initial)

Varga, L

5. DATE OF PUBLICATION (month and year of publication of document) November 2004	6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.) 15	6b. NO. OF REFS (total cited in document) 3

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

DRDC Ottawa

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant) 11au15	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)
10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Ottawa TM 2004-265	10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(x) Unlimited distribution
(   ) Distribution limited to defence departments and defence contractors; further distribution only as approved
(   ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
(   ) Distribution limited to government departments and agencies; further distribution only as approved
(   ) Distribution limited to defence departments; further distribution only as approved
(   ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

Unlimited

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

A method enabling the control of the radar signature using metamaterial is presented. The work was carried out using a Multiradius Bridge Current (MBC) Electromagnetic Moment Method code. The metamaterial specimen in this work is a 2D array of vertical wire segments each loaded with resistor and inductor. The results indicate that the far field directional gain of the metamaterial differs from the specular far field directional gain of a wire mesh. In case of the metamaterial, the far field directional gain can be rotated in azimuth with respect to the direction of the incoming incident wave. The results are discussed in term of activated segment line selected from the array of segments that make up the metamaterial specimen.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Metamaterial, Antenna, Resonators, L-C circuits, Far field, Directional gain, Wire mesh

Defence R&D Canada

Canada's leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

www.drdc-rddc.gc.ca